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RESEARCH ARTICLE

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New Species and New Record of Genus *Chrysothrix* (Chrysotrichaceae, Arthoniales) from South Korea and Chile

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ABSTRACT

The genus *Chrysothrix* is very common around the world and easy to be recognized by its bright yellowish granular thallus. In this study, investigations of lichen mycota in South Korea and Chile from 2010 to 2017 have been done, and some *Chrysothrix* specimens were collected, based on the morphological and chemical study on these specimens, five species were confirmed in this study, including one new species from Chile, *Chrysothrix chilensis* D. Liu & J.-S Hur, and one new record from South Korea, *C. xanthina* (Vain.) Kalb. Meanwhile, detail description and illustration for each species were present in this study.

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1. Introduction

The lichen genus *Chrysothrix* Mont. is characterized by the yellow, lemon to bright yellow, or golden yellow leprose thallus or apothecia, *Arthonia*-type asci with 3–7 (rare 1–2) septate spores, and presence of pulvinic acid derivatives (i.e., calycin, vulpinic, and pinastric acid) in thallus, which makes this group easy to be recognized. *Chrysothrix* usually grows on rock, tree, and wood, and has a wide distribution around the world, like Europe, North America, Australia, South America, and India [1–8]. Prior to this study, this genus comprised ca. 20 species, two of which have been reported in South Korea, *C. candelaris* and *C. chlorina* [9–11], and three in Chile, *C. candelaris*, *C. granulosa*, and *C. pavonii* [8,12].

During investigation of lichen flora in Chile (2013) and South Korea (2010–2017), several specimens of *Chrysothrix* were collected, and then morphological and chemical studies were performed in this study, and we aim to clarify species information of this genus in these two areas.

2. Materials and methods

2.1. Chrysothrix *samples collection*

All the specimens in this study were collected from 2010 to 2017 in different sites of South Korea and Chile, and all of these specimens have been deposited in Korea National Arboretum, Pocheon, South Korea (KH) at present.

2.2. Morphological examination

The morphological and anatomical characteristics of the specimens were examined under a dissecting microscope (Nikon SMZ 745 T; Tokyo, Japan) and Olympus BX 50 microscope (Olympus, Tokyo, Japan). Photos were taken under HD-Measure LTHS-300 (Leetech Co., Seoul, South Korea) microscope and Carl Zeiss MicroImaging with Axio Cam ERc 5 s imaging system (Carl Zeiss MicroImaging, GmbH, Gottingen, Germany). All measurements based on the sections from thallus and apothecia were made in the water. Minimum-maximum values and the maximum value are recorded for granule, asci, and ascospores size. The number (*N*) of granules, asci, and spores were measured, and mean values (in italics), standard deviations (S.D.), quotient of length and width (*Q*), and average quotient [*Q* (m)] were calculated. The terminology to describe leprose lichens follows Lendemer [13].

2.3. Chemical analysis

UV test were performed under the UV Chamber (VL-6.LC, Vilber Lourmat Sté, Collégien, France). Secondary metabolites were detected according to the spot tests and thin layer chromatography (TLC) in solvent C system followed by Elix [14], Orange et al. [15], and Culberson and Kristinsson [16]. *Lethariella cladonioides* (Nyl.) Krog and standard vulpinic acid (Cat#: V850000; Toronto Research Chemicals Inc., Ontario, Canada) were used as control.

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3. Results

Based on the morphological and chemical data, we reported four species in Chile, including one new species, namely *C. candelaris*, *C. chilensis* D. Liu & J.-S. Hur. sp. nov., *C. granulosa*, *C. pavonii*, and two species in Korea, *C. candelaris* and new record *C. xanthina*.

3.1. Chrysothrix candelaris *(L.) J.R. Laundon*

Morphology: Thallus corticolous, thin, crustose-leprose, granules bright yellow to orange-yellow, usually with orange tinge, scattered, continuous or slightly pseudo-areolate, or aggregating into small patch, granules (29.9–)30–*50*–60(–70) µm, $N = 20$, S.D. = 8 µm; thallus ecorticate, margin not delimitation, hypothallus absent; photobiont chlorococcoid, round, 6–15 µm in diam; hyphae hyaline 1–1.5 µm wide; apothecia and pycnidia not seen (Figure 1(A,B)).

Chemistry: K–, C–, KC–, PD–, UV–. Contain calycin (major).

Ecology and distribution: This species always grows on the bark, especially on the open conifers forest, and companies with species of *Lepraria* and *Buellia*. This species is worldwide.

Examined specimens: CHILE. Patagonia, Torres del Paine, Y290 5–10 km, 51°34′37″S, 72°35′59″W, 133 m, on bark of *Nothofagus* sp., 17 Jan 2013, S.-O. Oh & J. S. Hur CL130063. SOUTH KOREA. Jeollanam-do: Jangheung-gun, Gwansan-eup, Okdang-

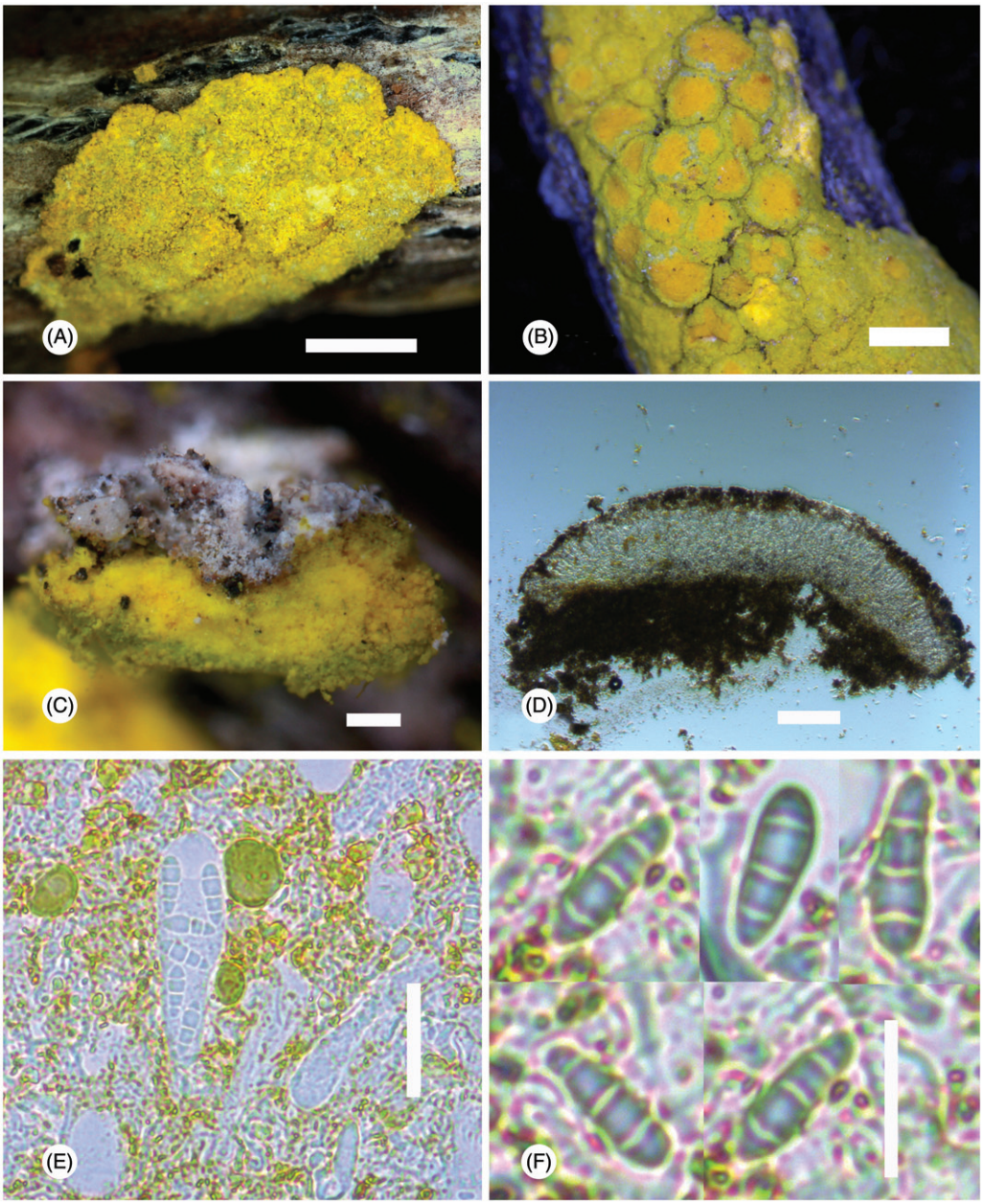

Figure 1. Species of *Chrysothrix* in South Korea and Chile. (A) *Chrysothrix candelaris* (L. Lőkös & S. Kondratyuk 150831); (B) Section of *C. candelaris*; (C) *Chrysothrix chilensis* (S.-O. Oh & J. S. Hur CL130432); (D) white hypothallus of *Chrysothrix chilensis*; (E) *Chrysothrix xanthina* (scale bars: A, E = 0.3 mm, B, F = 20 µm, C, D = 0.5 mm, E, F = 1 mm).

ri, Cheongwansan Mts, near the entrance, 34°32'55"N, 126°55'60"E, 91 m, on bark of *Pinus* sp., 23 Jun 2015, S. Kondratyuk & L. Lőkös 150413; Suncheon-si, Seokhyeon-dong, Hyanglimsa, 34°58′20″N, 127°28′43″, 46 m, on *Quercus*, 4 Oct 2017, D. Liu 171425. Gangwon-do, Sacheon-myeon, Gadunji-gil, small pine plantation along the seashore road (Haean-ro) at Sacheon Beach, 37°49′43″N, 128°52′41″E, 5 m, on bark of *Pinus* spp., July 9 2015, S. Kondratyuk & L. Lőkös 150831.

Remarks: *Chrysothrix candelaris* is sterile in our specimens and characterized by its bright yellow, diffuse, leprose thallus, which usually aggregates into small patch, containing calycin. This species has been recorded from Jeju Island and mainland of Korea [10,11].

3.2. Chrysothrix chilensis *D. Liu & J.-S Hur, sp. nov.*

Mycobank #823353.

Diagnosis: Similar with the *C. granulosa*, but differs in having white hypothallus and containing Chry 2.

Type: Chile, Cuesta Bvenos Ayres, 29°35′11″S, 71°14′53″W, 257 m, on branch, 13 Nov2013, S.-O. Oh & J. S. Hur CL130432.

Morphology: Thallus byssoid, clossly attached substrate, effused to slight placodioid, 0.2–5 cm across, up to 0.8 mm thick; upper surface granuliform, lemon yellow to bright yellow, greenish yellow sometimes, granules (20)30–*40*–50 µm, $N = 48$, S.D. = 8 µm; ecorticate; margin usaully not delimitation; hypothallus usually one layer, white, soft, loose, byssoid, sometimes with yellow dots; hyphae rough, beseting with numerous, short yellow crystals, 1–2.3 µm wide; photobiont Chlorococcoid, alga cells round, 6–19 µm; apothecia not seen (Figure 1(C,D)).

Chemistry: K–, KC–, C–, PD–, or pale orange. Contain calycin (major) and Chry 2 (major), gyrophoric acid (minor); substance Chry 2 has following characters: located in class 4(–5), after spraying and heating, spot becomes orange center with dark orange edge, UV + orange.

Ecology and distribution: This species always grows on the bark, adjacent lichen groups including *Ramalina* spp., *Roccella* spp. This species usually overlaps with *C. granulosa*.

Etymology: The epithet "chilensis" refers to country where the species was found.

Additional examined specimens: CHILE, Cuesta Bvenos Ayres, 29°35′12″S, 71°14′53″W, 257 m, on branch, November 13 2013, S.-O. Oh & J. S. Hur CL130433, CL130482.

Remarks: This species is characterized by placodioid or byssoid thallus, and most similar with *C. granulosa*, but differs from latter species in having a yellow to golden yellow hypothallus (treat as medulla by Thor [8], contains substance Chry 2. This species sometimes mixed overlap with the species *C. pavonii* and *C. granulosa*, but they can be distinguished by thallus and hypothallus type, *C. pavonii* micro-fruticose, whereas *C. granulosa* having a golden yellow hypothallus. Thor [8] recorded three chemotypes [8], but specimens of *C. granulosa*-group containing Chry 1 often have larger granules and golden yellow hypothallus based on our examination.

3.3. Chrysothrix granulosa *G. Thor*

Morphology: Thallus byssoid, closely attached substrate, effused to slight placodioid, 0.2–6 cm across, up to 1 mm thick; upper surface granuliform, lemon yellow to bright yellow, greenish yellow sometimes, granules (20)30–*50*–70(100) µm, $N = 45$, S.D. = 15 µm. thallus margin usually delimitation; prothallus absent; hypothallus usually one layer, golden yellow, sometimes two layers, the second layer white to silvery, soft, loose, byssoid; hyphae rough, besetting with numerous, short yellow crystals, 1–3 µm wide; photobiont Chlorococcoid, alga cells round, 6–17 µm (Figure 2).

Apothecia rare, round, with constricted base, immerse into thallus when young, raise to the thallus surface when mature, 0.23–0.81 mm; disc yellowish pruinose, flat to convex, brown orange; exciple poorly development; hymenium 70–80 µm thick; asci clavate, 8-spored, (35.9–)36.7–*41*–48.7 (–50.6) × (8.4–)9.3–*11.9*–11.2 (–11.3) µm, $N = 15$; paraphysis simple to branch, not swollen at tip; ascospores obovoid, straight to slight curved, 3-septate, rare 2 septate, thin wall, hyaline. (8.9–)9.1–*10.8*–12.5(–12.8), Q (m) = 3.44, $N = 51$, S.D. (L) = 0.96 µm, S.D. (W) = 0.56 µm.

Chemistry: K– or red, KC–, C–, PD– or pale orange, UV–. Contain calycin and Chy 1 [8], substains Chry 1 characters: class 5(–6) in C, after spraying and heating, spot becomes yellow center with dark orange edge, UV + orange.

Ecology and distribution: This species always grows on bark or wood. Adjacent lichens including *Flavoparmelia caperata*, *Buellia*, *Ramalina*, *Roccella*, *Usenea,* and *Xanthoria* spp. This species usually distributes along the coast from central Chile to Northern Peru, Australia, and New Zealand [3,8].

Examined specimens: CHILE. Cuesta Bvenos ayres, 29°35′12″S, 71°14′53″W, 257 m, on branch, November 13 2013, S.-O. Oh & J. S. Hur CL130420; Caleta Tototal Baja, 28°17′16″S, 71°10′38″W, 203 m, on branch, November 14 2013, S.-O. Oh & J. S. Hur CL130527; Fray Jorge National Park, La Serena,

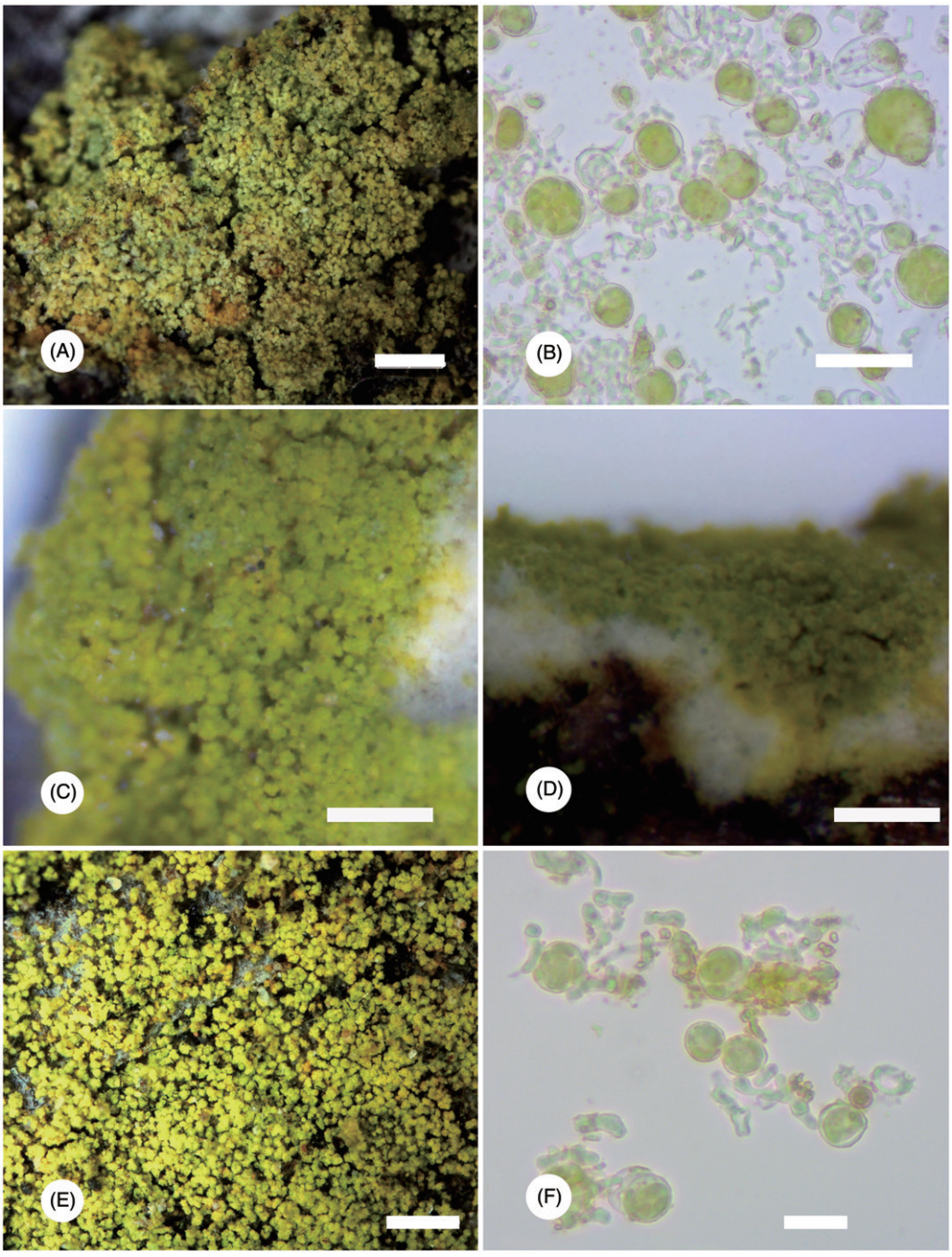

Figure 2. Morphology of *Chrysothrix granulosa* (S.-O. Oh & J. -S. Hur CL130420). (A) Thallus; (B) apothecia; (C) hypothallus; (D) section of apothecia; (E) asci; (F) ascospore (scale bars: A, B = 1 mm, C = 0.2 mm, D = 100 µm, E = 20 µm, F = 10 µm).

30°37′32″S, 71°39′46″W, 279 m, on branch, November 15 2013, S.-O. Oh & J. S. Hur CL130551.

Remarks: This species is characterized by having slightly placodioid granular thallus and golden yellow hypothallus (treated as medulla by Thor [8]).

3.4. Chrysothrix pavonii *(Fr.) J.R. Laundon*

Morphology: Thallus fruticose-leprose to micro-fruticose, composed of numerous fine, richly interwoven, branched filaments, forming irregular to globose cluster, 5 mm across; filaments hyaline to golden yellow, most part golden yellow due to besetting with numerous, short yellow crystals; thallus margin, granules, prothallus, and hypothallus absent; photobiont converging into a mass, and sparsely mixed and adhere on the filaments, Chlorococcoid, alga cells round, 8–18 µm; hyphae hyaline, 2–5 µm wide, often beset with many crystals (Figure 3).

Apothecia not common, scattered to clustered, pseudolecanora-type, inconspicuous, usually covered by thallus, reaching to surface when mature, 1–2 mm in diam.; disc plane, soft, golden yellow, usually yellowish pruinose; margin surrounded by the byssaceous thallus, fluffy, and alga cluster can be observed; exciple not well-developed; hypothecium brown-orange; asci clavate, 8-spored, (27.4–)30.5–*36.7*–45(–45.5) × (6.4–)7.7–*8.6*–10.9

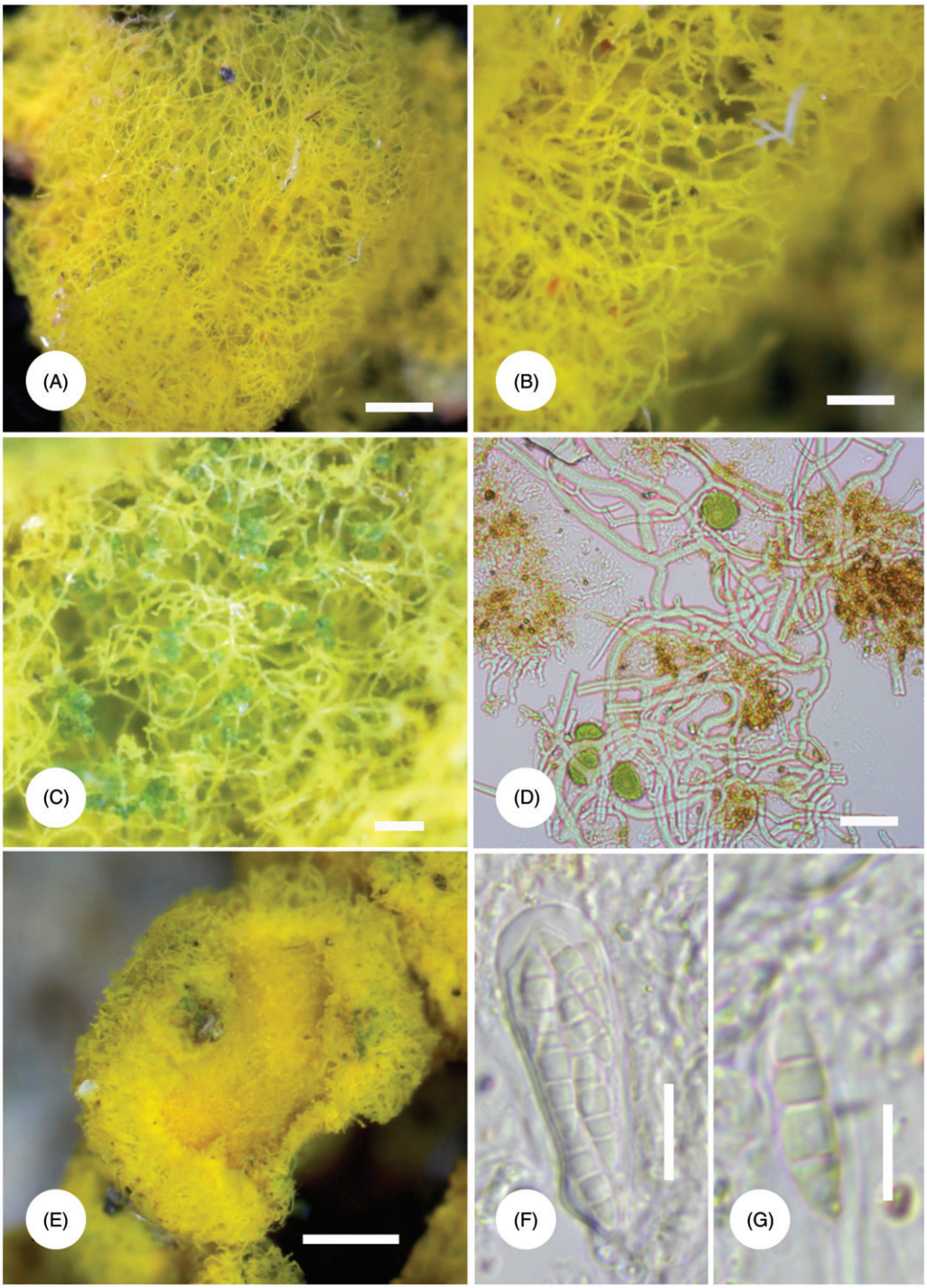

Figure 3. Morphology of *Chrysothrix pavonii* (S.-O. Oh & J. -S. Hur CL130368). (A) Thallus; (B) filaments besetting short crystals; (C) alga cluster; (D) hyphae; (E) apothecia; (F) asci; (G) ascospore (scale bars: A = 0.2 mm, B, C = 0.1 mm, D = 20 µm, E = 0.5 mm, F, G = 5 µm).

(–11.2) µm, $N = 15$; paraphyses sparsely, colorless, septate, simple to branch, not swollen at tip, 1 µm wide; ascospores *Arthonia*-type, obovoid, sometimes curved, hyaline, 3-septate, rare 2-septate, (9.4–)9.5–*12.2*–14.4(–14.6) × (2–)2.2–*2.7*–3.3(–3.3) µm, Q(m) = 4.59, S.D. (L) = 1.5 µm, S.D. (W) = 0.37 µm, $N = 39$.

Chemistry: Thallus K–, C–, KC–, P–. Contain calycin.

Ecology and distribution: This species always grows on branches of spiny shrubs and their axils. It distributes along the west coast parts of Chile.

Examined specimen: CHILE, La Serena, 29°43′55.9″S, 071°19′11.2″W, 115 m, on the axils of the cactus spines, November 12 2013, S.-O. Oh & J. S. Hur CL130368.

Remarks: This species is characterized by the micro-fruticose and fibroid thallus, and containing calycin as the major and single secondary metabolites.

3.5. Chrysothrix xanthina *(Vain.) Kalb*

Morphology: Thallus thin, crustose-leprose, granules yellow to lemon yellow, scattered, continuous, not

areolate, granules (20–)30–*40*–50(–60) µm, $N = 42$, S.D. = 8 µm; prothallus thin and hyaline, extend outward from or adnate the granule; thallus ecorticate, margin and hypothallus absent; photobiont chlorococcoid, round, 7–15 µm in diam.; hyphae hyaline 1–1.5 µm wide; apothecia and pycnidia not seen (Figure 1(E,F)).

Chemistry: K–, C–, KC–, PD–, UV–. Contain pinastric acid (major).

Ecology and distribution: This species usually grows on the bark, especially on the open conifers forest, sometimes on a rock in South Korea, and companies with *Graphis* and *Phaeophyscia*. It has been reported in Australia, North America, and Malaysia [6].

Examined specimens: SOUTH KOREA. Gyeongsangbuk-do, Uljin-gun, Jukbyeon-myeon, Jukbyeon-ri, Jukbyeon10-gil, roadside trees along street Jukbyeonjungang-ro., 37°03′27″N, 129°25′04″E, 10 m, on bark of *Cerasus* sp., *Metasequoia glyptostroboides*, July 11 2015, S. Kondratyuk & L. Lőkös 151362; Gyeongsangnam-do, Yangsan-si, Wondong-myeon, 35°25′30.91″N, 128°56′16.51″E, 150 m, on rock, D. Liu 152674, 152675; Jeju-do, Seogwipo-si, Andeok-myeon, Sagye-ri, Mt.Sanbang, 33°14′14.2″N, 126°18′47.7″E, 101 m, on bark, July 5 2012, L. Lőkös et al. 121435. Jeollanam-do: Suncheon-si, Seokhyeon-dong, Hyanglimsa, 34°58′20″N, 127°28′43″, 46 m, on *Pinus*, October 4 2017, D. Liu 171424; Wando-gun, Bogil-myeon, Bogil Island, Yesong-ri, near Yesong beach trail, 34°08′30.2″N, 126°33′48″E, 2 m, on bark of *Pinus* sp., February 6 2010, Y. Joshi et al. 100237; Gurye-gun, Gwangui-myeon, Gumanje-ro, on bark of *Pinus*, September 20 2013, Y.C. Chung 130819.

Remarks: *Chrysothrix xanthina* is recognized by its lemon yellow, diffuse, leprose thallus, granules 30–50 µm, contain pinastric acid. *Chrysothrix xanthina* was separated as a new combination species from *C. candelaris* by Kalb [6], based on the granules size (20–50 µm in diam.), tropical region distribution, and containing pinastric acid. This species has been reported from the subtropical area [3,4,17] and been a new record in South Korea in this study.

4. Discussion

Thallus morphology variation is rather great in genus *Chrysothrix*. From micro-fruticose like *C. pavonii*, to byssoid and placodioid type in *C. granulosa* and *C. chilensis*, or granular type like *C. candelaris* and *C. xanthina*, they can be easily recognized and distinguished by the bright yellowish color, *Arthonia*-type ascospores, and distinctly different type thallus.

However, it is rather difficult to differ from each other when they share similar type thallus, for this case, chemical analysis becomes a significant identical character, which was widely used the granular group of *Chrysothrix* [1–4]. Besides chemical substance, the substrate was also treated as a very important point to distinguish species, i.e., *C. pavonii* prefers spiny shrubs and *C. candelaris* usually found on coniferous or oak bark, whereas *C. chrysophthalma* and *C. chlorina* frequently saxicolous [12]. For the sorediate or granular species, the apothecia usually not common, then the size of the granule ideally used to separate species, nevertheless, it becomes rather ambiguous when the size overlaps, so molecular analysis may be a potential method to explain the natural relationship in genus *Chrysothrix* if we can get the good conditional specimens.

Disclosure statement

No potential conflict of interest was reported by the authors.

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